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Some alternative views of energy

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This article describes some views of the concept of energy from two main standpoints: that of the science teacher and that of the youngsters learning science in school. It enters into a growing debate about the content of school science and the means by which it might be taught (see for example recent letters from J W Warren and P E Richmond *Phys. Educ.* 1983 **18** 55–6). There is an adage that physics is the study of energy in its many forms. It would certainly be difficult to find any course in science where energy does not play *some* part—if it is not a central theme. New curriculum proposals see it as a major feature in the core of science instruction at primary level (DES 1982) and at secondary level (GCE and CSE Boards Joint Council 1982). And yet such enthusiasm is not wholesale. For example, Warren (1982) makes an earnest plea for teachers to *eliminate* the word energy entirely from early science teaching. He argues that it should appear only in advanced work and then be firmly based upon the concept of work. There is growing evidence that many of the words used in physics are not unproblematic—including the term work (Gilbert and Osborne 1980, Duit 1981)—even for advanced students.

One source of difficulty arises from the failure of teachers to acknowledge that students have well developed ideas around many of the words in science, long before formal teaching of the ideas takes place. Such ideas and meanings for words are not simply isolated misconceptions, but are part of a complex structure which provides a sensible and coherent explanation of the world from the youngster's point of view. As Richmond (1982) so aptly points out, energy means different things to different people. So do gravity (Watts 1982a), force (Watts 1982b), heat and pressure (Engel 1982) and many more. These explanatory perspectives have been called 'alternative frameworks' after the work of Driver and Easley (1978). The study of students' frameworks is based upon the assumption that if youngsters' conceptions of energy are to grow into the more sophisticated understanding of the physicist (as Richmond suggests) then we must first establish what sorts of conceptions they may *have*.

Table 1 School students interviewed

Number	*Age*	*Name*	*Science group*
01	14	Colin	3rd year general science
02	15	Margaret	4th year CSE physics
03	15	Susie	4th year O-level physics
04	14	Jane	3rd year general science
05	15	Jonathon	4th year O-level science
06	16	Jane	5th year O-level physics
07	17	Andrew	6th form A-level physics
08	18	Keith	6th form A-level physics
09	16	Gillian	5th year CSE physics

The frameworks discussed here stem from a series of interviews based upon the interview-about-instances approach (Gilbert *et al* 1982). In outline, the IAI technique consists of a series of line drawings that depict various situations where the concept of energy may (or may not) be thought to be involved. The pictures contain a variety of clear cut examples and some 'borderline cases'—being unusual or unorthodox applications of the word from the physics point of view.

The students are asked to decide if the pictured situations illustrate *their* concept of energy and to give a reason why. Their reasons are probed using, whenever possible, the language the pupils use to describe the situations. Some examples are shown in figure 1. The participants in these energy interviews have been third-year (general science), fourth- and fifth-year (O-level and CSE physics) and sixth-form (A-level physics) students at secondary schools in and around the Greater London area. The total number of interviews is about forty. The frameworks are illustrated here using extracts taken from the transcripts of the students' responses. Further details are shown in table 1.

The frameworks described are *not* an exhaustive list of the conceptions verbalised by school students. In many cases the term energy forms part of a loose descriptive and interpretative network of ideas. At some times it is used synonymously with words like force or power (Watts and Gilbert 1982a). These frameworks are offered as examples

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of the most popular and persistent ones intimated and disclosed during the interviews. They are currently being substantiated by two further studies (Gilbert and Pope 1982, Watts and Gilbert 1982b). The frameworks are as described below.

Framework 1

'Human centred' energy. Many of the descriptions that youngsters give when describing energy are very anthropocentric and anthropomorphic. That is, they see energy to be associated mainly with human beings, or treat objects as if they had human attributes. This is true of all ages and although advanced students sometimes adopt the traditional 'third person passive' register of physics, they find it difficult to maintain. Considering the example of a person pushing a box up a hill, a typical response would centre on the person as having energy, but certainly not the box:

Susie 'The person's got a lot of energy in that one . . . I mean he can push it the whole way up to the top of the hill . . . but, er, once the box is there it can't *do* anything so the box definitely hasn't got any energy . . . whereas the person can walk away back down'. (03:15)

(Here the numbers at the end of the quote refer to the *number* of the interview and the *age* of the interviewee, so (03:15) refers to the third interview, which was with a 15-year-old.)

Stead (1980) has found very similar tendencies with school children in New Zealand and calls it the 'everyday' sense of the word. She notes that most of the children interviewed related the word energy to living things by way of being 'energetic'. Anthropomorphism consists of seeing inanimate objects as being alive or sometimes as 'wanting' to do something. For example:

Jane 'They (two reacting chemicals) have energy *in* them . . . I mean they don't go around talking to things . . . But I mean they've got energy in them . . . so I suppose in their own sort of way they are living'. (06:16)

Discussions about human beings can, of course, be seen as evidence for some of the other frameworks to follow. The tendency to consider *only* the human actors in a situation, though, is very pervasive.

Framework 2

A 'depository' model of energy. This is a model of energy that Clement (1978) calls a 'source of force' model. From this point of view, youngsters see some objects as having energy (and being rechargeable), some as 'needing' energy (and simply expending what they get) and yet others as neutral (and whose activities are somehow 'normal' or 'natural'). Energy, then, is a causal agent, a source of activity based or stored within certain objects.

Colin '. . . water . . . if we didn't have water . . . water is a source of energy . . . we need it to survive . . . (later) . . . water has got something to do with this too (a power station) I think it is powering the generators'. (01:14)

Margaret 'Well the battery's *got* the energy . . . the bulb *needs* it and the wires . . . well they're just ordinary wires aren't they'. (02:15)

The 'sources' can sometimes be human, or something else—like the battery in the last extract or as in:

Jonathon 'Energy . . . well you have to *have* energy and store it . . . and then use it up . . . you get it from oil . . . petrol . . . the sun . . . anything that's *got* it'. (05:15)

This idea of energy has a long history (see Elkana 1974). The 'power' within things that enables them to act has often been called energy. If something happens, then it seems natural to look for some source that causes it. It is, however, a long way from the complex mathematical treatment for what the physicist means.

Framework 3

Energy is an 'ingredient'. In this framework energy is not necessarily a causal agent, but a 'reactive' one. It is a dormant ingredient within objects or situations that needs some 'trigger' to release it. Solomon (1980) notes this feature when pupils talk about food: 'pupils believe that energy is *not* stored in food, it only "gives you energy when you eat it"'.

Jane 'Well there is energy *in* things . . . it's there but it needs another energy to . . . sort of . . . another form of energy to make it come out . . . it's like a seed, it's got energy inside it to grow but it needs the sun . . . well, one chemical needs another chemical to make it react'. (04:14)

In a similar way some would argue that energy is not *stored* in coal or oil (as in framework 2) but is 'sparked off' when either is burnt. Likewise, a book lying upon a table would not have energy—unless something (or someone) came along to push it off.

Framework 4

Energy is an 'obvious' activity. To many, it is outward overt displays of activity that are the sole means of identifying energy. Moreover, the activities themselves are actually called energy. Movement (of any kind) is widely given as a reason for energy being involved: the energy *is* the movement itself. This is often indicated, in the responses, by energy being equated with a verb, a word-of-action. (*I* represents the interviewer.)

I 'What sort of examples of energy would *you*

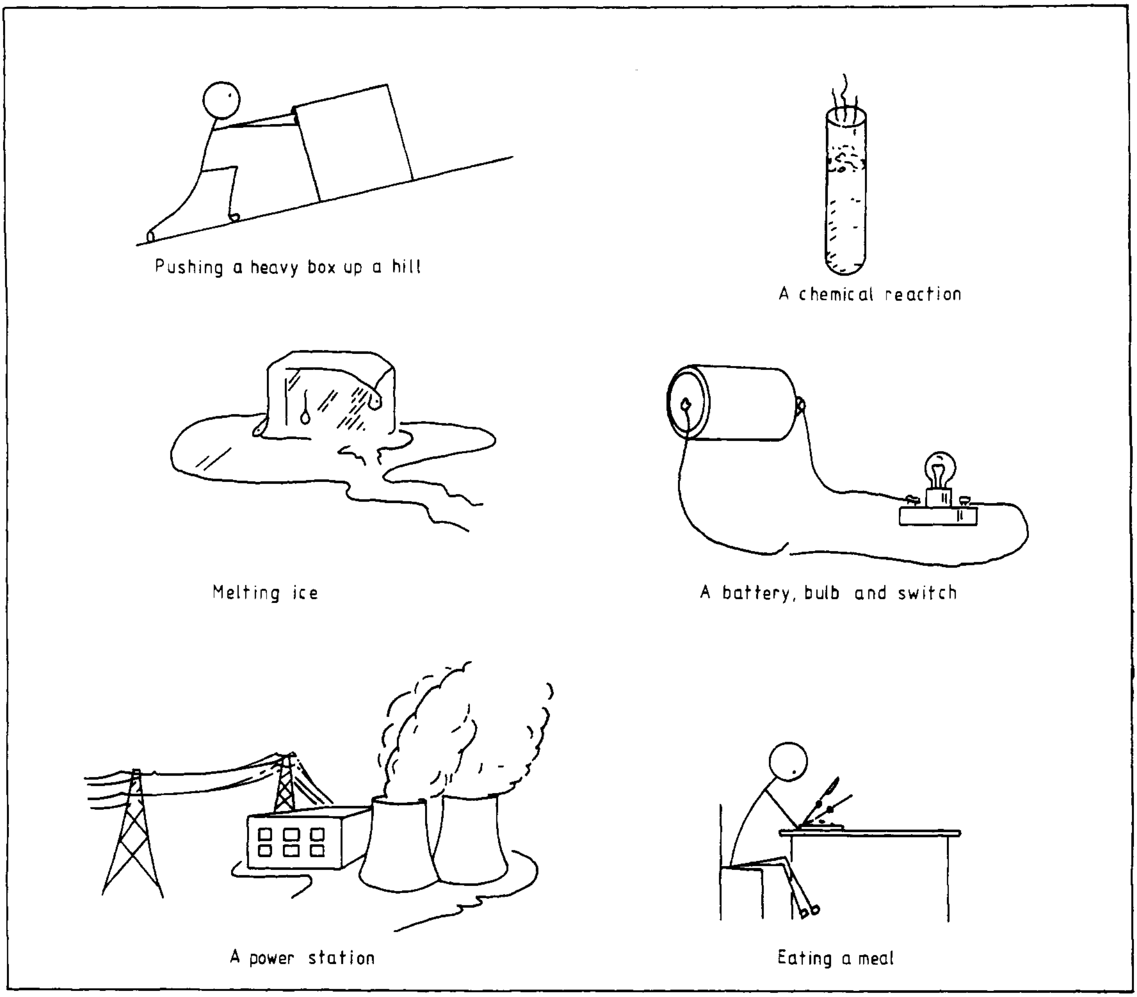

Figure 1 Some examples of the energy cards

give?'

Jane 'A fire burning . . . a telephone ringing . . . chemicals frothing . . . people running . . . that sort of thing'. (06:16)

This framework is similar to the everyday meaning of the word. It is not seen as the cause of the action, but as the occurrence itself.

Gillian 'The sledge is . . . is creating energy by moving fast'. (09:16)

Framework 5

Energy is a product. In contrast, this framework carries the suggestion that energy is not an ingredient or a process (as above) but a byproduct of the situation. In some senses it was rather like a waste product as with smoke, sweat or exhaust fumes—another perspective identified by Stead (1980). Clearly energy is non-conserved, as with the other frameworks, and here it is treated as a relatively short-lived product that is generated, is active and then disappears or fades.

Andrew 'They (some chemicals) might change . . . in which case they'll release some of their energy and produce heat . . . in this vapour here'. (07:17)

Keith 'Well as it (ice) melts it will give off heat . . . as the bonds break between the atoms . . . and roll over each other . . . the heat will be given off . . . so it produces heat energy'. (08:18)

The second extract is interesting on two counts. Not only is it an example of energy being produced and 'given off', it also suggests that the bonds between atoms being broken results in energy being released rather than increased.

Framework 6

Energy is functional. In many instances energy is seen as a very general kind of fuel, with some limitations. Firstly energy is more or less restricted to technical appliances and secondly is not essential to all processes but is mainly associated with those that make life more comfortable. As Duit (1981) says: 'for a life without technical aids it seems no energy would be needed'. This framework carries a suggestion of why energy might be an important concept (but without its general applicability); for these youngsters, energy is deliberately contrived to be useful, and it is not a descriptive measure.

I 'Has the box any energy?'

Jonathon 'No because the person's doing all the work pushing it upwards . . . if *that* had any energy it could help him'.

I 'What would you say energy was?'

Jonathon 'Something that can *do* something for us . . . say like gas or something . . . (later) . . . energy has got to make something else *work* . . . like if it was electrical it would make something like that tape recorder work'. (05:15)

Needless to say, one of the problems with introducing the term work is that its everyday connotations will carry over into meanings of energy. Cars, aircraft, ships, drills, etc, have energy; falling books, clouds and so on do not work for us, and so would not have.

Framework 7

A flow-transfer model of energy. Aarons (1965) says 'Energy is not a substance, fluid, paint or fuel which is smeared on bodies, rubbed off from one to another; we use this term to denote a construct—numbers calculated in a certain prescribed way, that are found by theory and experiment to preserve a remarkably simple relationship in very diverse physical phenomena'.

And yet Warren (1982) points out that 'energy is a fluid' *is* both an implicit and explicit suggestion behind the way in which the concept is commonly taught in schools. In this way energy is seen as being 'put in', 'given', 'transported', 'conducted' and so on.

Keith '. . . the energy comes out from both leads . . . because you never get a circuit without the other one . . . it comes out of the negative end . . . flows round the circuit . . . encountering the light bulb on the way . . . where it can transfer some of the energy . . . and goes back to the battery'.

I 'Oh?'.

Keith 'The energy is *on* the electrons as they travel round'. (08:18)

Duit (1981) notes that a considerable number of his sample of secondary school children strongly associated energy with the 'flow' of electricity. In some cases a pictorial image of energy as a flowing, or fluid, substance has been deliberately used in order to introduce the concept (Schmid 1982) or as being 'carried' by electroparticles (Härtel 1982).

Summary

It is important to recognise that the frameworks here are not meant to categorise youngsters in the way they think. They are a useful means of analysing and describing the complex responses they provide as they discuss the concept of energy. Viennot's (1979) work has shown that formal teaching is not always successful at changing students' ideas. In her study, Engel (1982) found a confusing picture of conceptual change in fourth- and fifth-year pupils—certainly no clear-cut pattern of acceptance of (or growth towards) scientific ideas because of classroom teaching.

The debate about the teaching of energy is not a new one, as the letters columns of the long established journals testify. Certainly if youngsters are to be encouraged to undergo conceptual change towards the scientific view, then both the content and practice of science education must change. Conceptual change, one might say, is two way. Pupils' ideas must be valued and built on. Interesting examples are Solomon's (1982) development of 'useless' energy, Schmid's (1982) 'energy carriers' and Härtel's (1982) circuitry. The frameworks described here are not the full range of possible ones. Rather than simply speculate at quite what students understand by it all, we have to begin to find out. Then both student and teacher can come to know both their own—and each other's—meanings for energy.

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Apollo chart

The non-profit-making Pictorial Charts Educational Trust (27 Kirchen Road, West Ealing, London W13 0UD) continues to extend its product range. *The Moon-Apollo Exploration* (chart + booklet, price £3.20 + VAT) is one of six new packages. It comprises a large (1000 mm × 750 mm) full colour wall poster and a copyright-free A5 booklet of notes, written by Dr Anthony Wilson.

Although the chart consists of a dozen beautiful big pictures, it is rather a rag-bag—there is no developing theme and no links between the pictures. (Indeed it is not always clear which caption refers to which illustration.) Perhaps it is just to be viewed casually, or as wallpaper? The notes are quite excellent, however. They describe missions and equipment in detail and are very readable and cohesive.

Moon exploration is dead now, interest in the outer planets coming to replace it as a field for human endeavour. Apollo is history as far as most of us are concerned. This is a nice way to teach history!

Eric Deeson

Measurements of some properties of non-Hookean springs

G Lancaster

In the first year laboratory in the Physics Department at Keele University we have for several years introduced the students to experimental method via the medium of 'class' experiments: the students, working in pairs, carry out the same experiment. There are frequent interludes to allow class discussions of experimental planning, provisional error estimations, and discussions of the interpretation and significance of measurements. The classes number between 40 and 50 students and so the availability of apparatus and space and considerations of cost dictate that the experiments should involve simple apparatus and cheap materials.

An experiment which we have used in recent years and which we regard as having been successful is an investigation of the static and dynamic properties of a helical steel spring. In the first part of the experiment the length l is measured for a spring suspended vertically and having a load M attached to its lower end. The property 'force per unit strain' s is defined for the spring and determined from the slope of the graph of l versus M. In the second part of the experiment the period T of vertical oscillations of a loaded spring is measured and s is determined from the slope of the graph of T^2 versus M. The values of s determined by the static and dynamic methods are compared to see whether they agree to within experimental error; this implies, of course, that realistic estimates of experimental errors have been made.

Pedagogically the interest in the experiment arises from that fact that the behaviour of the springs is non-Hookean at small loads, a feature of which the students are not forewarned and which is

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